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Topographics of dry skin, non-dry skin, and cosmetically treated dry skin as quantified by skin profilometry

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Synopsis

Skin profilometry is a noninvasive instrumental method which has been used to quantify the topography of human skin. Profiles of the skin's topography are generated by tracing over a replica of the skin's surface with a stylus instrument. These profiles, which represent cross-sectional views of the cutaneous relief, are analyzed to calculate the values of selected parameters which are used to quantify surface characteristics.

Skin profilometry was used to characterize the topographies of clinically dry skin and non-dry skin on the lateral surface of the lower leg. Two parameters were selected to quantify the textures of these two skin conditions: number of peaks in the profile and mean peak size. The effect of a skin-care cosmetic on dry skin of the lower leg was also investigated.

The number of peaks was significantly higher for non-dry skin than for dry skin and no differences were detected for mean peak size. Cosmetically treated dry skin was characterized by a larger number of peaks following treatment and no significant changes in mean peak size were observed following treatment.

Microscopic examination of the skin replicas revealed that non-dry skin is characterized by a more uniform distribution of criss-crossing furrows than dry skin. These furrows result in division of the skin surface into more plateaus (peaks) for non-dry skin than dry skin. The effect observed for the cosmetic product used for these studies was the re-establishment of uniform texture to dry skin following treatment.

INTRODUCTION

Quantitative studies of the skin's surface topography have been made possible by the transfer of surface analysis technologies from the metals- and space-industries to dermatology and cosmetic science. These technologies, profilometry and image analysis, have led to valuable research instruments for the skin researcher (1,2) and in the near future may provide the clinician additional tools for objective and quantitative diagnoses of skin disorders as well as a means for assessing responses of dermatoses to treatments.

We have used skin profilometry to investigate the geometric characteristics of the skin's surface. Skin profilometry is a method by which profiles of the skin's surface are obtained by tracing the surface of a replica of the skin with a stylus instrument. As the stylus is moved across the replica's surface, its vertical motion is converted into electrical signals. Plots of these signals versus horizontal displacement of the stylus are called profilograms and represent cross-sectional views of the skin's uppermost boundary (Figure 1). Roughness parameters, mathematical quantities which can be interpreted

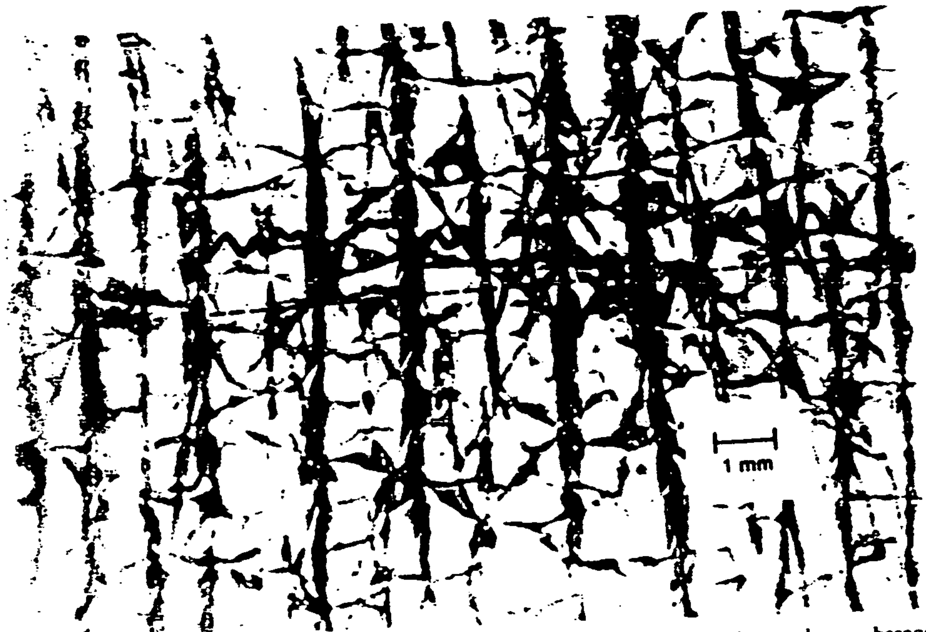

Figure 1. A typical profilogram of the dorsal surface of the hand is shown superimposed on a photograph of the area of the cast which was scanned (dashed line) with the profilometer. The horizontal magnification is approximately the same for the profilogram and photograph. The correlation between the profile characteristics and geometric detail on the surface is evident.

geometrically from the surface profiles, are used to quantify the surface measurements. Studies conducted in our laboratory and those of others have shown that at many sites on the body the skin's surface topography is anisotropic, with major furrows running in preferred directions (3,4). These patterns vary over the body's surface (5) and are a function of the age of the subject (6–8).

In this paper we report the results of three studies, two of which were designed to investigate differences in topography between dry skin and non-dry skin, and a third, designed to investigate the effect of a skin-care cosmetic on the topography of dry skin.

MATERIALS AND METHODS

SUBJECT SELECTION

Two studies designed to investigate differences between the topography of dry skin and the topography of non-dry skin were conducted, one during December 1980 and one during December 1981. The test site was the lateral aspect of the lower leg. In the first of these studies (December 1980), twelve subjects with non-dry skin and eleven subjects with dry skin (mean age of each group was 29 years) were selected from a group of Caucasian female subjects between the ages of 25 and 35 years. In the second dry skin study (December 1981), ten subjects with non-dry skin and eight subjects with dry skin (mean age per group was 37 years) were selected from a group of Caucasian female subjects (none of whom participated in the December 1980 study) between the ages of 32 and 42 years.

A scoring system was used to distinguish individuals with dry skin from those with non-dry skin based on visual assessment of lower leg skin as follows: 0 = no symptoms of dry skin; 1 = ashiness but no discernible flakes; 2 = small to medium flakes; and 3 = large flakes and prominent "cracked glass pattern."

All subjects were required to stop using cosmetic preparations on their legs for three weeks prior to our evaluation of skin condition and selection of subjects. All subjects who did not clearly fit into either the dry skin group (score = 3) or the non-dry skin group (score = 0) were eliminated from the studies.

The study designed to investigate the effect of a skin-care cosmetic* on the topography of dry skin was conducted during December 1981. The subjects were selected in the identical fashion as described above for the dry skin studies. Ten female subjects with dry skin (mean age of 38 years, age range 32 to 40 years) were recruited. One leg per subject was randomly picked for treatment with the skin-care product; the other leg served as an untreated control. The product was applied, at a rate of approximately 2 mg cm^{-2}, to the lateral aspect of the lower leg chosen for treatment, each morning and each evening after bathing, for 21 days. The subjects' legs were shaved in the laboratory with an electric shaver at the beginning of the study, periodically throughout the study, and on the last day of treatment.

In an attempt to minimize the transfer of product from the treated leg to the untreated control leg, each subject was instructed to wash the control leg before washing the treated leg and to wear long-legged pajamas to bed.

REPLICATION PROCEDURE

Silicone rubber impressions (Silflo®, Flexico Developments Ltd.) of the skin's surface pattern were taken from the lateral aspect of one leg of each of the subjects participating in the dry/non-dry comparison studies.

In the 21-day treatment study, impressions were taken from the lateral aspect of both legs before treatment began and again 24 hours after the last application of the skin-care product.

Epoxy casts (Embed 812®) were made of each impression.

SCANNING PROCEDURE

A profilometer (Surfometer SF101) with a stylus having a diameter of 20 microns was used to make six one-centimeter-long scans approximately 0.5 cm apart over the surface of each cast. Because of previous demonstrations of the dependence of surface profile characteristics on direction of scan, three scans were run perpendicular to the predominant furrows present on the surface and three scans were run parallel to this detail. Each surface profile generated (1500 data points/cm) was quantified by computing the values of the roughness parameters, number of peaks, R_N (the number of peaks per centimeter), and mean peak size, R_m (3).

* Visible Difference Moisture Cream Complex®. See Table I.

Table I
Visible Difference Moisture Cream Complex® Ingredient Listing

Water
Emulsifying Wax
Glycerin
Isopropyl Myristate
Squalane
Beeswax
Panthenol
Imidazolidinyl Urea
Allantoin
Methylparaben
Propylparaben
Olive Oil
Retinyl Palmitate
Fragrance
Sodium Borate

We have set two criteria which must be met before the distance between a local minimum (LMIN) and a local maximum (LMAX) on the profile can be considered a peak (Figure 2). The first criterion states that the difference between a LMIN and a LMAX must be greater than or equal to a preselected value (α) before the difference can be considered for peak classification, i.e.,

$$d_i \geqq \alpha \tag{i}$$

where d_i is the vertical distance between a LMIN and a LMAX and is defined as a significant step specified in microns.

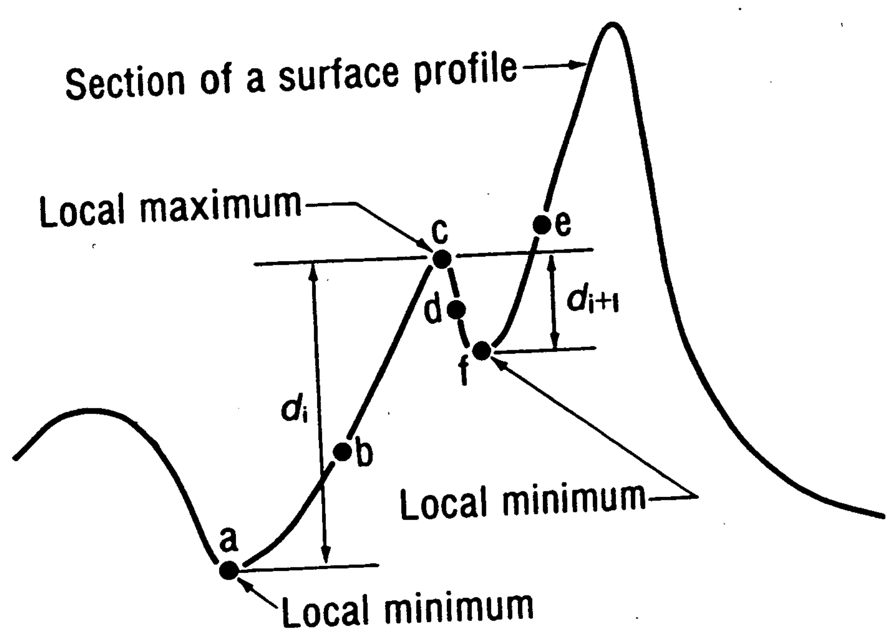

Figure 2. Data analysis.

The second criterion states (Figure 2) that after a LMAX is reached, the vertical distance (d_{i+1}) between it and the next LMIN must be a preselected portion (β) of the distance between the previous LMIN and LMAX before the distance, d_i, can be classified as a peak and recorded as the peak's height, i.e.,

$$\text{if } d_{i+1} \geqq \beta d_i, \text{ then } d_i = \text{peak} \tag{ii}$$

If equation (iii), the peak factor criterion, is not satisfied before a new LMAX is reached, then the distance, d_{i+1}, is recorded as the peak's height, i.e.,

$$\text{if } d_{i+1} < \beta d_i, \text{ then } d_{i+1} = \text{peak.} \tag{iii}$$

An example of the logic used when establishing peaks based on the criteria given above follows (refer to Fig. 2). The data is processed from left to right until a local minimum, a, is identified. Point a is recorded as a local minimum when point b is reached, where the distance, $\overline{ab}$, b > a, satisfies the significant step criterion (ii). Once the local minimum is established, the processing continues until a local maximum, c, is identified. Point c is recorded as a local maximum when point d is reached, where the distance, $\overline{cd}$, c > d, satisfies the significant step criterion (ii). The remaining data is then processed until the peak factor criterion (iii) is satisfied or a rise in the curve occurs such that a point e is reached where e > c. If the peak factor criterion is satisfied, then the vertical distance, $\overline{ac} = d_i$, is recorded as the peak's height and the processing continues until a new local minimum, f, is reached and the entire process starts again. If point e is reached before the peak factor criterion is satisfied, then the data points between c and e are searched for a local minimum, f, and the vertical distance, $\overline{cf} = d_{i+1}$, is recorded as the peak's height (iv). The process then continues with point a remaining as the local minimum. The procedure continues until all 1500 data points are processed. The data is processed a second time (right to left) so that any bias resulting from the way in which the cast was run is removed.

After the peaks are identified and their sizes recorded, the roughness parameter, number of peaks, R_N, and mean peak size, R_m, are computed, where R_N equals the total number of peaks recorded and R_m equals the geometric mean of all peak heights recorded.

All the data presented in this report have been generated with α = 3 microns and β = 0.5. The data acquisition and reduction was performed by a PDP 11/45 computer which interfaces directly with the profilometer.

RESULTS

Based on previous studies (3) and our experience with skin profilometry, we have selected the roughness parameters, number of peaks, and mean peak size to quantify the topography of dry skin, non-dry skin, and treated dry skin. Descriptive statistics for these parameters are presented in Tables II and III.

The results of an analysis of variance contrasting the roughness parameters for dry and non-dry skin (each of the studies analyzed independently) and untreated and treated skin are given, in terms of a p-value, in the last column of Tables II and III.

Since skin condition was found to be independent of direction of scan (Table IV), the six within-cast values for each roughness parameter were averaged for each subject, and

Table II
Descriptive Statistics and Results of Analysis of Variance for Dry Skin and Non-dry Skin

December 1980

Roughness Parameter	Mean ± s.d.		P-Value
	Dry Skin	Non-dry Skin	
Number of Peaks, R_N	51.98 ± 4.72	62.72 ± 7.85	< 0.001
Mean Peak Size, R_m (μm)	23.41 ± 4.60	24.75 ± 6.40	> 0.500

December 1981

Roughness Parameter	Mean ± s.d.		P-Value
	Dry Skin	Non-dry Skin	
Number of Peaks R_N	48.69 ± 3.84	56.55 ± 7.12	0.013
Mean Peak Size, R_m (μm)	26.23 ± 7.54	24.48 ± 4.61	> 0.500

Table III
Descriptive Statistics and Results of Analysis of Variance for Treated Dry Skin

Roughness Parameter	Mean ± s.d.		P-value
	Control	Treated	
Number of Peaks, R_N before treatment	48.52 ± 3.80	48.88 ± 5.33	> 0.500
Number of Peaks, R_N after treatment	51.67 ± 6.29	60.02 ± 5.98	0.025
Mean Peak Size, R_m (μm) before treatment	20.22 ± 2.94	20.28 ± 2.99	> 0.500
Mean Peak Size, R_m (μm) after treatment	20.78 ± 3.49	20.69 ± 3.26	> 0.500

these averages were used to calculate the means and standard deviations compiled in Table II. The change in the parameter R_m following treatment was a function of direction of scan (Table IV). This interaction is reflected in the smaller value of R_m for the normal direction of scan for the treated legs than for the control legs, while the opposite is true for the parallel direction of scan (Table V). However, since neither difference between control and treated legs was significant (Table V), we felt comfortable averaging the six within-cast values for R_m and using these averages to calculate the means and standard deviations given in Table III.

In both dry skin studies, the number of peaks, R_N, was found to be significantly lower when comparing dry skin to non-dry skin (Table II). This difference is independent of direction of scan (Table IV). The mean size of peaks, R_m, does not appear to change as a function of dry skin condition; however additional analysis of the distribution of the peaks by their sizes revealed that dry skin tends to be characterized by a larger number of peaks greater than 70 microns in size than does non-dry skin. Peak distribution data are presented for the December 1981 dry/non-dry study in Figures 3 and 4 for both the normal and parallel directions of scan, respectively. The observed ten-

Table IV
Results of an Analysis of Variance for Direction by Condition or Treatment Interactions

Study	Interaction	Parameter	p-Value
December 1980	Condition × Direction	R_N	0.340
		R_m	0.165
December 1981	Condition × Direction	R_N	0.582
		R_m	0.221
December 1981	Treatment × Direction	R_N	0.996
		R_m	0.027

dency is present in the normal direction only. The dry/non-dry differences in peak size distribution were not statistically significant.

In the 21-day treatment study, no differences were present between the values of the roughness parameters for the control legs and treated legs before treatment began ($P > 0.500$). Twenty-four hours following the 21-day treatment period, the number of peaks, R_N, was significantly greater on the treated legs (Table III). The increase in R_N was found to be independent of direction of scan (Table IV). The mean size of the peaks, R_m, was not significantly changed by the treatment ($P > 0.500$).

DISCUSSION

In areas other than the palmar surface, the skin's surface pattern has received a limited amount of scientific inquiry. We believe this to be the result of a lack of quantitative methods of investigation. Skin profilometry has filled this void and has recently been used by several investigators to study various aspects of the skin's surface pattern (3,5,9,10).

In these studies we have investigated both the differences in the skin's surface pattern between subjects with dry or non-dry skin on their lower legs and the effects of a cosmetic treatment on this pattern. The skin's topography appears to be composed of two major geometric characteristics: the surface pattern or microrelief, and squamae or desquamating flakes. The former is the pattern of furrows criss-crossing the surface and creating a network of peaks. Superimposed on this pattern are the flakes. In dry skin, these flakes are larger and more numerous than in non-dry skin.

We have found in this investigation that in addition to increased flakiness, dry skin is characterized by a diminution of the surface pattern; the number of peaks is reduced

Table V
Values of the Roughness Parameter Mean Peak Size, R_m, by Direction of Scan

Direction of Scan*	Mean ± s.d.		p-Value
	Control	Treated	
Normal	25.78 ± 4.30	23.26 ± 2.46	0.064
Parallel	15.78 ± 3.77	18.11 ± 4.96	0.264

* Directions are specified relative to the direction of major furrows.

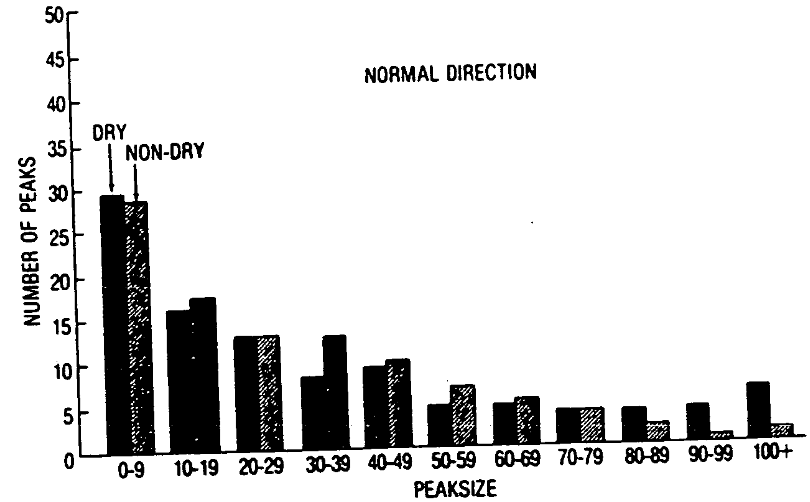

Figure 3. Peak distribution by size for normal direction of scan.

by approximately 15 percent. This is a reflection of broader plateaus between the furrows.

Representative profilograms for dry skin, non-dry skin, and treated dry skin are shown in Figure 5. For non-dry skin, the surface profile is composed of a well-defined, fairly uniform array of peaks and valleys. A less-definite, shallow profile is typical of dry skin. The transition from a well-defined surface pattern typical of non-dry skin to a less-definite pattern typical of dry skin is reflected in the roughness parameter number

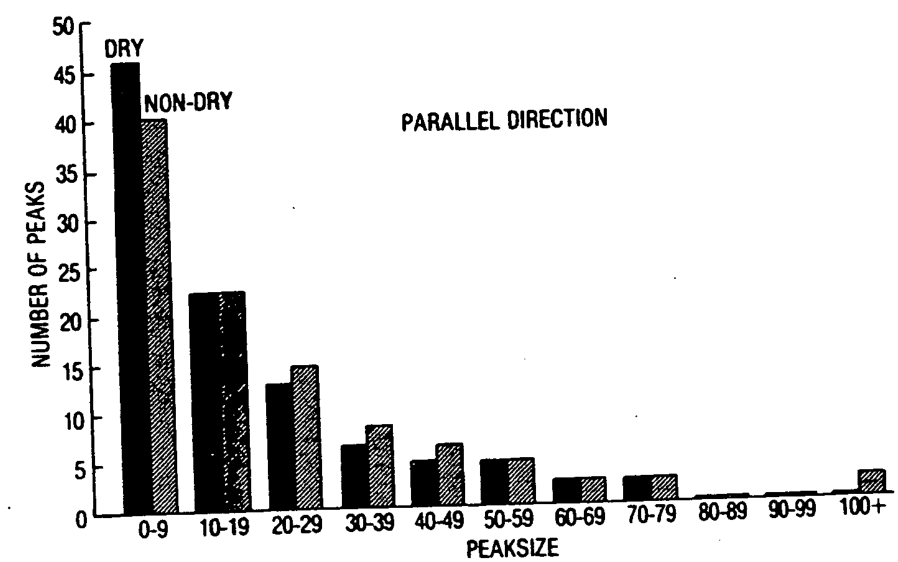

Figure 4. Peak distribution by size for parallel direction of scan.

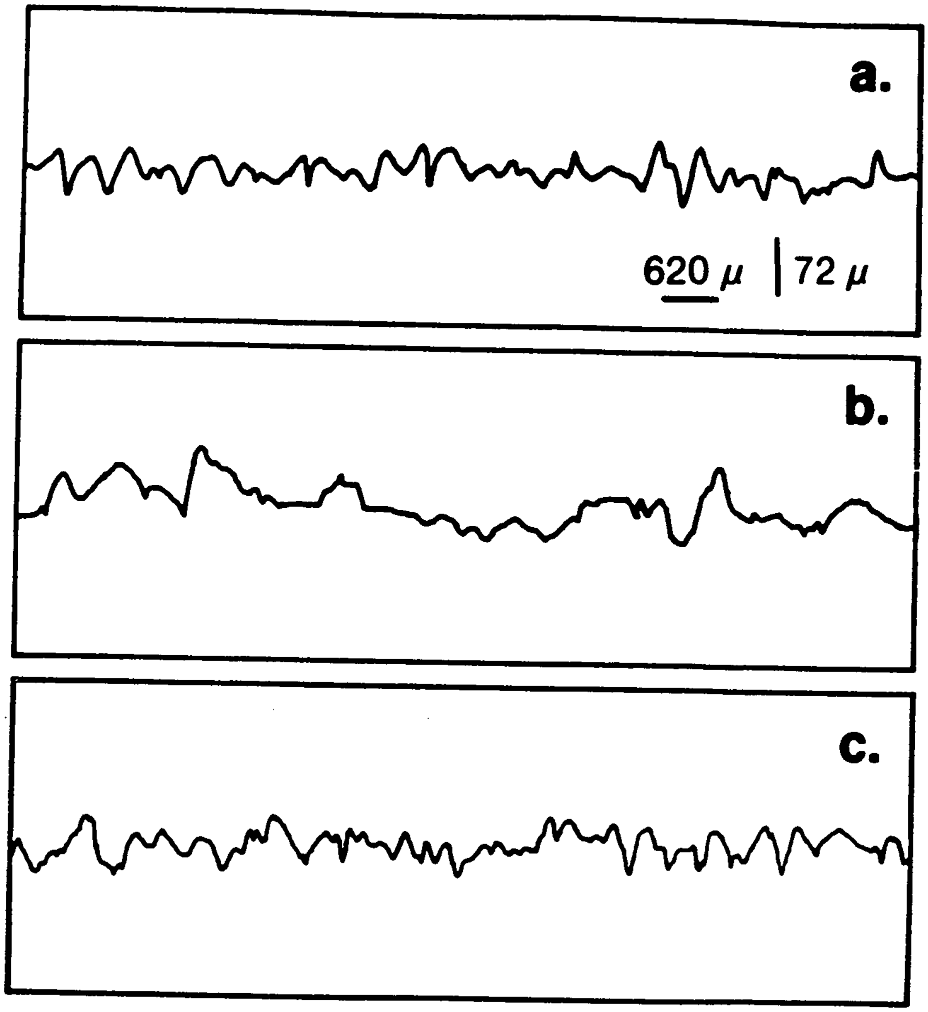

Figure 5. A typical profilogram of non-dry skin (a); a typical profilogram of dry skin (b); a typical profilogram of dry skin which was treated with a cosmetic for 21 days (c).

of peaks. The skin-care cosmetic used in this study restored to dry skin the well-defined surface pattern typical of non-dry skin, as was also evidenced by the increase in R_N for treated dry skin.

Whether the differences in skin's topography we have reported are a reflection of epidermal variables, dermal variables, or a combination of the two is not known (8, 11). Our future investigations are directed toward examination of the possible relationships between the skin's surface pattern and the morphology of the epidermal-dermal junction.

ACKNOWLEDGMENTS

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